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APPLICATION NUMBER: *60/482,099*
FILING DATE: *June 24, 2003*

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PATENT APPLICATION SERIAL NO. ____________

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FEE RECORD SHEET

06/26/2003 SDENBOB1 00000098 141270 60482099
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PTO-1556
(5/87)

*U.S. Government Printing Office: 2002 — 489-267/69033

PROVISIONAL APPLICATION COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION under 37 CFR 1.53(b)(2).

Docket Number US030190		Type a plus sign (+) inside this box	+

INVENTOR(s)/ APPLICANT(s)

LAST NAME	FIRST NAME	MIDDLE INITIAL	RESIDENCE (CITY AND EITHER STATE OR FOREIGN COUNTRY)
Mazniev	Alexei		Marblehead, MA

TITLE OF THE INVENTION (280 characters max)

OPTOACOUSTIC METHOD FOR MEASURING SURFACE PROFILE ON STRUCTURES CHARACTERIZED BY SUB-MICRON LATERAL FEATURE SIZE

CORRESPONDENCE ADDRESS

Philips Intellectual
Property & Standard
345 Scarborough Road
P.O. Box 3001
Briarcliff Manor, NY 10510-8001

STATE	New York	ZIP CODE	10510	COUNTRY	U.S.A.

ENCLOSED APPLICATION PARTS (check all that apply)

X	Specification	Number of Pages	10		Small Entity Statement
X	Drawing(s)	Number of Sheets	2		Other (specify)

METHOD OF PAYMENT (check one)

	A check or money order is enclosed to cover the Provisional filing fees	PROVISIONAL FILING FEE AMOUNT ($)	$160.00
X	The Commissioner is hereby authorized to charge filing fees and credit Deposit Account Number: 14-1270		

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The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

[x] No,

[ ] Yes, the name of the U.S. Government agency and the Government contract number are:

Respectfully submitted,

SIGNATURE ____ Date 6/24/03

TYPED or PRINTED NAME AARON WAXLER REGISTRATON NO. 48,027

[ ] Additional inventors are being named on separately numbered sheets attached hereto

CERTIFICATE OF EXPRESS MAILING

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I hereby certify that this paper and/or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 C.F.R. 1.10 on the date indicated above and is addressed to the Commissioner for Patents, Alexandria VA. 22313-*1450

Burnett James	Burnett James
Typed Name	Signature

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	Atty. Docket
ALEXEI MAZNEV	US030190
Serial No.:	Group Art Unit No.:
Filed: CONCURRENTLY	

Title: OPTOACOUSTIC METHOD FORD MEASURING SUDRFACE PROFILE ON STRUCTURES CHARCTERIZED BY SUB-MICRON LATERAL FEATURE SIZE

Commissioner for Patents
Alexandria, VA 22313-1450

AUTHORIZATION PURSUANT TO 37 CFR §1.136(a)(3)
AND TO CHARGE DEPOSIT ACCOUNT

Sir:

The Commissioner is hereby requested and authorized to treat any concurrent or future reply in this application requiring a petition for extension of time for its timely submission, as incorporating a petition for extension of time for the appropriate length of time.

Please charge any additional fees which may now or in the future be required in this application, including extension of time fees, but excluding the issue fee unless explicitly requested to do so, and credit any overpayment, to Deposit Account No. 14-1270.

Respectfully submitted,

By ______________________

Aaron Waxler, Reg. 48,027
Patent Agent
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DISCLOSURE OF INVENTION

THIS DESCRIPTION SHOULD BE SUPPLEMENTED BY ATTACHING COPIES OF RELEVANT DOCUMENTS, SUCH AS PUBLISHED ARTICLES OR PATENTS, PRODUCT BROCHURES, ENGINEERING NOTEBOOK PAGES AND DRAWINGS.

DESCRIPTIVE TITLE OF THE INVENTION: Optoacoustic method for measuring surface profile on structures characterized by sub-micron lateral feature size

INVENTOR #1: Alexei Maznev | Sr. Scientist | Philips Analytical, Supply Center Boston
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Revision June 11, 2001

1. PRIMARY CONTACT
Who should CIP contact for further technical information about the invention and information about its planned use or public disclosure?

Inventor Name: Alexei Maznev

2. PRESENT STAGE OF THE INVENTION

X Idea ☐ Research ☐ Development ☐ Manufacture

3. GOVERNMENT CONTRACT INVENTION

Was the invention made under a government contract? ☐ Yes X No

4. **PLEASE PROVIDE A TWO OR THREE SENTENCE SUMMARY OF YOUR INVENTION and include and underline KEY WORDS which might be useful in searching for relevant patents or publications:**

Photoacoustic transient grating technique also known as ISTS (Impulsive Stimulated Thermal Scattering) is applied to measuring profile of periodic structures with sub-micron feature size such as arrays of etched trenches. The measurement is based on the dependence of the surface acoustic wave velocity on the depth of the profile.

5. PRESENT STATE OF THE ART
Briefly describe the closest already-known technology that relates to the invention. This would include, for example, already existing products, methods or compositions which are known to you personally or through descriptions in publications.

1. ISTS technique implemented in Philips Analytical's Impulse/Emerald instruments is primarily used for film thickness measurement. It would be straightforward to use this technique to measure the etch depth of a film on a substrate if the size of the etched area is of the order of or larger than the probe laser spot i.e. typically ≥30 μm, in which case such measurement will be equivalent to measuring the film thickness inside and outside the etched area.

2. Scanning atomic force microscopy (AFM) is used to measure profile of sub-micron structures.
3. Scatterometry (measurement of the angular distribution of light scattered by the structure) is used to measure the surface profile of sub-micron structures. Unlike AFM, this is an indirect method based on the mathematical modeling of light scattering, and the feature size should be larger than at least a half of the optical wavelength.

4. An effect of periodic surface relief on the velocity of SAWs measured by the ISTS technique has been previously observed (see L. Dhar and J.A. Rogers, Appl. Phys. Lett. **77**, 1402 (2000)). However, it has not been proposed that the method could be used to measure the etch profile depth.

(ADD LINES AS NECESSARY, IF COMPLETING ON COMPUTER, OR ATTACH ADDITIONAL PAGES)

6. ADVANCEMENT IN STATE OF THE ART

Briefly describe the unique advancement achieved by the invention. This may be done, for example, by describing a problem with the prior art that is solved or specific objects that are achieved by the invention.

1. Unlike AFM and scatterometry, the proposed method does not have limitations related to high aspect ratio or small feature size of the structure
2. Compared to AFM, the method has an advantage of being an all-optical technique providing faster measurements and more suited for in-line process control. The profile depth is obtained in a single measurement vs. a linear scan needed in a measurement by AFM
3. Compared to scatterometry, the method has an advantage of simple and straightforward data analysis. The only measured parameter is the SAW frequency. Typically, the smaller the frequency, the larger is the profile depth.
4. The invention extends the range of applications of Impulse/Emerald film thickness measuring instruments.

ADD LINES AS NECESSARY, IF COMPLETING ON COMPUTER, OR ATTACH ADDITIONAL PAGES)

7. WHAT IS THE BEST WAY YOU KNOW OF TO IMPLEMENT THE INVENTION?

Briefly describe the invention and how it achieves the advancement described in paragraph 6

Attached on additional pages

(ADD LINES AS NECESSARY, IF COMPLETING ON COMPUTER, OR ATTACH ADDITIONAL PAGES)

*********PLEASE NOTE: IF WE DECIDE TO FILE AN APPLICATION ON THIS INVENTION, THE ATTORNEY WRITING THE APPLICATION WILL NEED THIS INFORMATION FROM YOU IN AS MUCH DETAIL AS POSSIBLE IN ORDER TO COMPLETE THE APPLICATION.**

8. DISCLOSURE OUTSIDE OF PHILIPS

If the invention has been or will be disclosed publicly or to anyone other than a Philips' employee, describe to whom (person / company), date and where.

The invention has not been disclosed outside of Philips

9. PUBLICATION

Has a description of the invention been published or submitted for publication? ☐ Yes X No

If "yes", please list each occurrence:

Date	Publication/Submission

10. **PLEASE INDICATE THE PRODUCT OR SERVICE IN WHICH YOUR INVENTION MOST LIKELY WILL BE USED:**
Philips Analytical's optoacoustic product line (Impulse/Emerald)

INVENTOR #1: A Mey 09/13/02
Signature Date

INVENTOR #2:
Signature Date

INVENTOR #3:
Signature Date

M asuring d pth of sub-micron tr nch arrays by ISTS

I. Outline of the m thod.

In the prior art, laser-induced transient grating technique, or ISTS, has been used to measure film thickness via measuring the phase velocity of Surface Acoustic Waves (SAWs) propagating in the filmstack. If the film is patterned e.g. by etching, it would be straightforward to use ISTS for measuring the etch depth if the size of the etched area is large compared to the SAW wavelength (typically 2-10 μm). In this case measuring the etch depth means simply measuring a change in the film thickness (see Fig.1). Note that it can only be done for a thin film on a substrate made of different material so that the SAW velocity be dependent on the film thickness. The prior art method will not work at all if one needs to measure surface profile of a bulk sample, e.g. a silicon wafer.

In the state-of-the-art integrated circuit manufacturing, typical pattern feature size is of the order of 0.1 μm i.e. much less than the SAW wavelength in an ISTS measurement. Although larger features may be also present within a die, it is the smallest features that are most likely to be misprocessed during lithography and etching, and, consequently, require process control metrology. According to the current invention, ISTS can be used to measure depth profile of a periodic structure with near- or sub-micron feature, e.g. a periodic array of trenches etched either in a thin film or in a silicon substrate (see Fig.1). The measurement is based on the fact that the SAW phase velocity is affected by periodic surface relief. This effect have been reported previously [1-2], but the application of the effect to measuring surface profile has not been proposed. Also, no studies have been done for high-aspect-ratio sub-micron structures which are of the most interest for practical applications.

According to the invented method, the measurement process is similar to an ISTS measurement known from the prior art, except of the fact that the excitation and detection of SAWs is performed on a patterned sample with surface profile characterized by a period of the order or less than 1 μm. The measurement yields the SAW frequency at a defined wavelength, from which the SAW phase velocity is calculated. The data are analyzed with the help of an analytical or empirical model to determine a parameter of the profile, typically the trench depth or width / space ratio.

II. Theor tical mod l for high aspect ratio tr nch arrays.

Previous theoretical work [1] was done for shallow surface relief permitting the use of perturbative approaches. Accurate analysis of high aspect ratio structures would require finite element calculations. Here, we are considering an approximate model in order to obtain at least an estimate of the effect of high aspect ratio trench array on SAW propagation. The model applies to periodic arrays of trenches such as those shown in Fig. 1 , with the period smaller than the trench depth. The model assumes that if the period of the structure is small with respect to both SAW wavelength and thickness of the structure, the structure can be treated as a homogeneous material with effective elastic properties. In Ref. [3], it was shown how to calculate the effective elastic properties of a layered structure from the properties of constituent materials. The layered structure is effectively described as a transversely isotropic medium with the symmetry axis perpendicular to the layers, which is described by 5 independent effective elastic constants. The same method can be applied to a trench array if vacuum is treated as one of the constituent materials of the structure. From the equations of Ref.[3], we obtain the following equations expressing effective density ρ^* and elastic constants C_{ij}^* of the trench array through the density ρ and elastic constants C_{ij} of the material:

$$\begin{aligned}
\rho^* &= h\rho \\
C_{11}^* &= h\left(C_{11} - \frac{C_{12}^2}{C_{11}}\right) \\
C_{66}^* &= hC_{44} \\
C_{13}^* &= C_{33}^* = C_{44}^* = 0
\end{aligned} \qquad (1)$$

where h is the ratio of the space between the trenches to the period of the structure. It can be expressed trough the trench width/space ratio as h=1/(1+w/s). The notations in Eq.(1) assume that the z-axis is perpendicular to the trenches.

For SAW propagation along the x-axis i.e. along the trenches, a transversely isotropic medium with the z symmetry axis is equivalent to an isotropic medium and the only elastics constants that matter are C^*_{11} and C^*_{66}. Therefore, a standard computer code for SAW propagation in a film/substrate structure can be used to analyze this case. Analysis of the propagation across the trenches is more complicated because some acoustic velocities are equal to zero and the standard code cannot handle the situation. For this case, I did a simplified analysis, modeling a trench array as a mass loading lacking any elastic strength.

Fig. 2 presents the calculated dependence of the SAW velocity on the trench depth for trench arrays with width/space ratios 1:1 and 1:3 fabricated in Si and in a 1 μm-thick thermal oxide film on

Si. The calculations were done for SAW wavelength 6 μm. The calculations show that there is a significant dependence of the SAW velocity on both the trench depth and width/space ratio, particularly for SAW propagation across the trenches. In order to estimate the repeatability of the trench depth measurements, let us assume that the repeatability of the SAW velocity measurements is ~0.5 m/s (which corresponds to the frequency measurement repeatability of 0.1 MHz). For a trench depth of 5000 Å and SAW propagation perpendicular to the trenches, the results presented in Fig.(2) yield a repeatability estimate of ~7 Å (or 0.14%) for 1:1 width/space ratio trenches in Si and ~20Å (or 0.4%) for trenches in the oxide film.

It should be noted that variations in trench depth and width have different effects on SAW velocity parallel and perpendicular to the trenches. An increase in the trench width increases the parallel velocity but decreases the perpendicular velocity while an increase in the trench width/space ratio increases the SAW velocity in both directions. This fact indicates that the measurements with SAW propagation along and across the trenches could be combined in order to determine both trench depth and width/space ratio.

III Experiment

Experiment was done at an acoustic wavelength of 6 μm on an array of 1 μm-wide trenches with 1:1 width/space ratio etched in an 8000 Å-thick layer of CVD oxide on Si, and covered with ~250 Å of PVD Ta and ~1000 Å of PVD Cu (see Fig.3). Note that this structure does not correspond to the theoretical model considered above because of the presence of the metal coating and also because the aspect ratio of the trenches is not high enough and the structure period is not too small compared to the wavelength. Therefore, the experiment was performed not in order to quantitatively verify the theoretical model but rather in order to demonstrate that a structure with deep trenches yields a good signal for SAW propagation direction both parallel and perpendicular to the trenches and also that there is a significant effect of the surface profile on the SAW velocity.

Fig. 4 presents the signal waveforms obtained in the unpatterned area of the sample and on the trench array with SAW propagation parallel and perpendicular to the trenches. It can be seen from the waveforms, that for the perpendicular propagation, the effect of the surface relief on the signal is particularly strong and that it causes a significant decrease in the SAW velocity. Table 1 lists the values of the SAW velocity obtained from the measured waveforms. The fact that the presence of the trenches increases the SAW velocity for the parallel propagation and decreases it for the perpendicular propagation qualitatively agrees with the theoretical model.

Reference

1. L. Giovannini et al., Phys. Rev. Lett. 69, 1572 (1992)
2. L. Dhar and J.A. Rogers, Appl. Phys. Lett, 77, 1402 (2000).
3. M. Gostein and A.A. Maznev, invention disclosure #703048

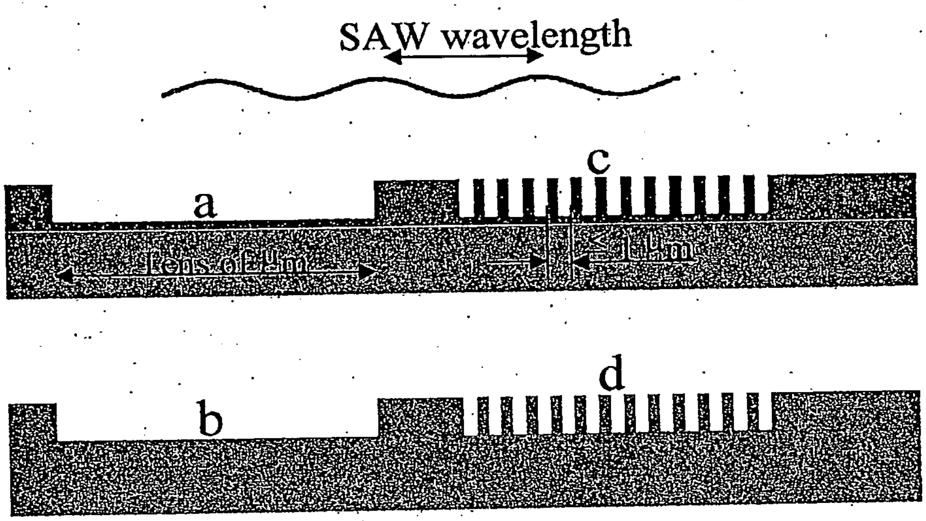

Fig. 1 Patterned film on a Si substrate (top) and patterned Si substrate (bottom).

The method proposed ion the invention measures the trench depth on structures (c) and (d). Structure (a) can be measured by a prior art method, structure (b) cannot be measured by ISTS as of now.

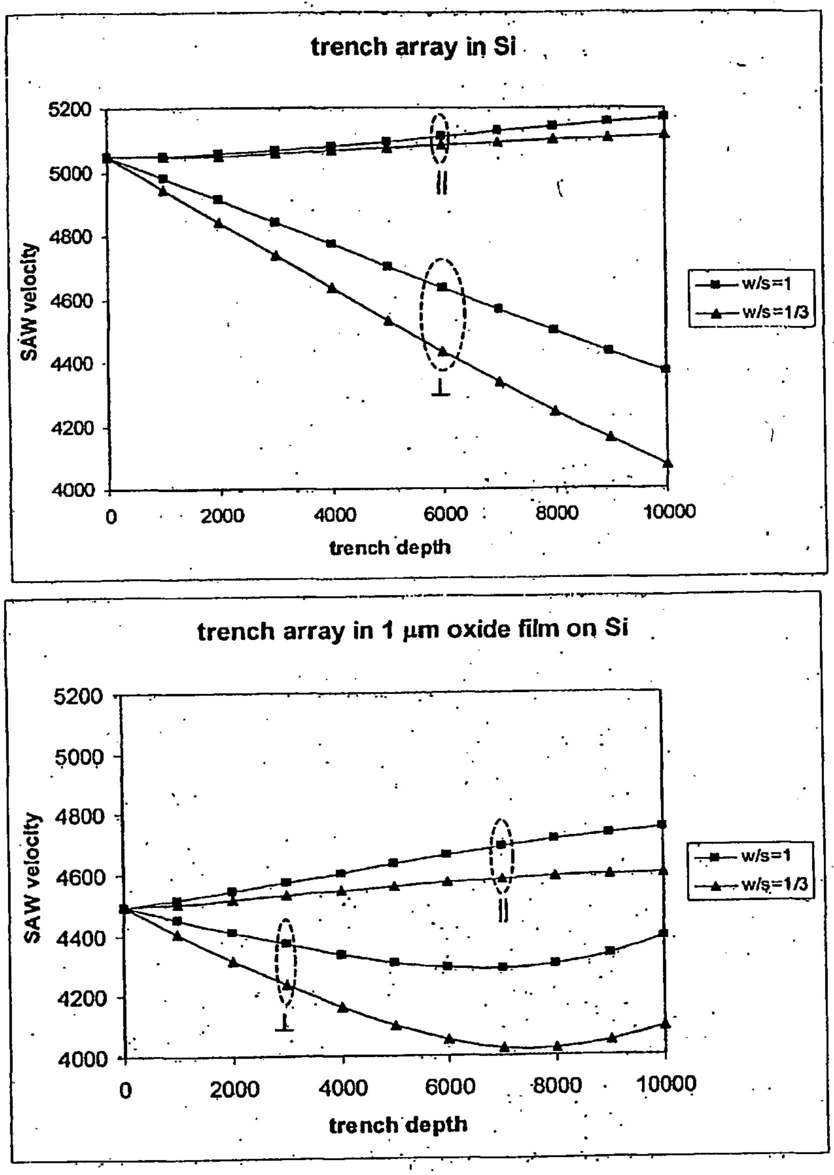

Fig.2 Calculated dependence of the SAW velocity on the trench depth for trench arrays with width/space ratios1:1 and 1:3 fabricated in Si (top) and 1 mm-thick thermal oxide film on a Si substrate (bottom) for SAW propagation parallel (||) and perpendicular (⊥) to the trenches.

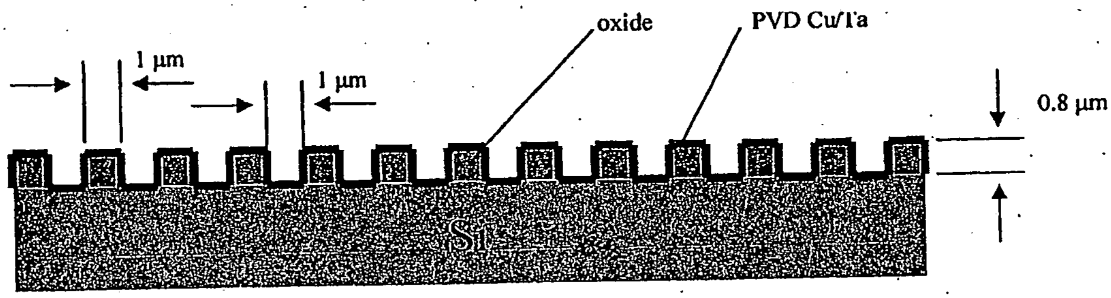

Fig. 3 Structure measured in the experiment

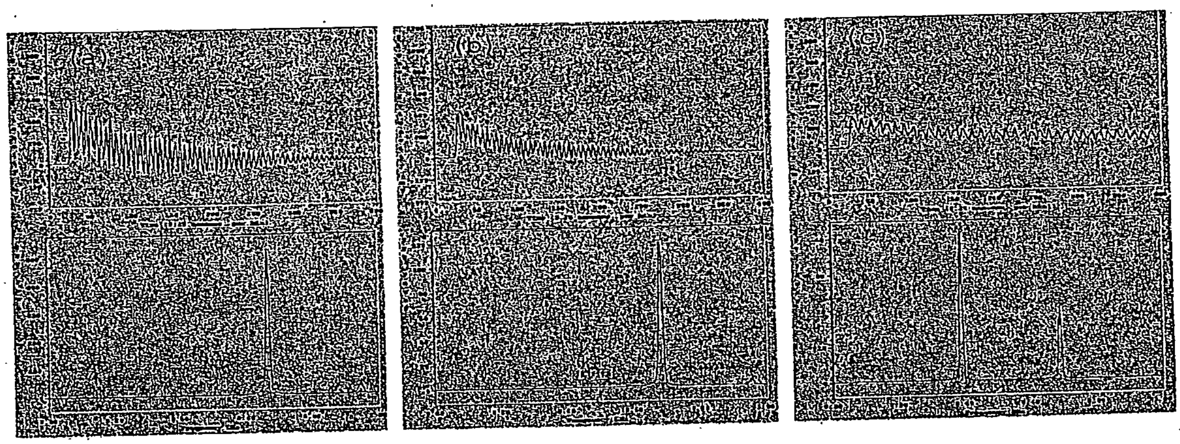

Fig. 4 Signal waveforms obtained at acoustic wavelength 6 μm on a sample with filmstack 1000 Å Cu / 250 Å Ta / 8000 Å oxide / Si. (a) unpatterned area of the sample, (b) 1 mm width x1 mm space trench array, SAW propagation parallel to the trenches; (c) SAW propagation perpendicular to the trenches.

M asurement location	SAW v locity (m/s)
Unpatterned area	3930
Trench array, parallel	4016
Trench array, perp ndicular	2299

Table 1. SAW velocities determined from the waveforms presented in Fig. 4